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# INTERIM REPORT
# UPPER KLAMATH LAKE STUDIES
# OREGON

U. S. DEPARTMENT OF THE INTERIOR

FEDERAL WATER POLLUTION CONTROL
ADMINISTRATION

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Algal species were identified and measured; during the period of the study Aphanizomenon flos-aquae represented about 90-99 percent of the total algal crop during the summer.

Limiting nutrient studies using the isotope Carbon-14 to measure variations in primary productivity were conducted in situ and in the laboratory; data from these studies were difficult to interpret.

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# INTERIM REPORT
# UPPER KLAMATH LAKE STUDIES
# OREGON

by

William E. Miller and Jerry C. Tash

Eutrophication
Research Branch
Pacific Northwest Water Laboratory
Corvallis, Oregon 97330

FEDERAL WATER POLLUTION CONTROL
ADMINISTRATION

September 1967

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# FOREWORD

Although historical records are incomplete, unwanted summer-time blooms of blue-green algae have appeared in Klamath Lake for many years. For this reason, and because of an interested local citizenry, the lake was considered a favorable site for research on eutrophication--the aging process in lakes. Moreover, the area is especially interesting from a scientific viewpoint because there is little cultural development on the watershed, the lake does not receive municipal sewage to provide nutrients for algae, and the lake remains uniformly mixed from top to bottom throughout the year. For these reasons, research was undertaken here to seek understanding of the basic mechanisms in production of blue-green algae. One of the first needs toward such objective is a clear picture of the input, use, and loss of nutrients in the lake. This has now been provided by the work completed thus far. The results, and how the research was done, are the subject of this report.

A. F. Bartsch
Chief, Eutrophication Research

## ABSTRACT

This report defines the water quality in Upper Klamath Lake watershed during the period March 1965 to April 1966. It identifies the sources of algal nutrients and other constituents in water flowing into and out of Upper Klamath Lake and compares the quantity of these constituents in pristine streams, canals, rivers, agricultural drainage, and springs. Chemical analyses were also made of algae, lake sediment, and bottom fauna samples. Algal species were identified and measured; during the period of the study Aphanizomenon flos-aquae represented about 90-99 percent of the total algal crop during the summer.

Limiting nutrient studies using the isotope Carbon-14 to measure variations in primary productivity were conducted in situ and in the laboratory; data from these studies were difficult to interpret.

INTERIM REPORT
UPPER KLAMATH LAKE STUDIES
OREGON

## INTRODUCTION

The Klamath Lake Project was initiated by the Pacific Northwest Water Laboratory in August 1964 to evaluate the nuisance algal blooms in Upper Klamath Lake and to gather information necessary for outlining economical, safe, and efficient methods for reducing or controlling the nuisance.

Various civic groups in Klamath Falls, Oregon, seeking a way to control the nuisance blooms of algae, interested the Public Health Service in the problem. The studies were continued under the Federal Water Pollution Control Administration after the Public Health Service functions on water pollution were transferred to that Administration. The Pacific Northwest Water Laboratory, Corvallis, Oregon, was assigned to investigate the problem and to suggest how it might be solved.

Klamath Lake had been studied with varying intensity for many years. Concentrated studies of the Klamath Lake algal nuisance originated from the Oregon State University Botanical Department in 1957 (18) which reported that nuisance blooms of algae, predominantly Aphanizomenon sp., occurred annually with no known control. After reviewing technical information available as of February 1962, a panel of experienced aquatic biologists concluded that: (a) chemical control of algal production in this lake would be uneconomical and dangerous; (b) algal control through introduction of biological agents has no scientific basis; (c) the magnitude of the job precludes harvesting of algae; (d) opportunities for curtailing algal nutrients are limited; and (e) control through artificially reducing light penetration would be both costly and dangerous. Personnel of the Pacific Northwest Water Laboratory and the Klamath Lake Project planned an experimental program to determine the validity of conclusion "d" in the light of technology developed since 1962.

The primary objectives of the Klamath Lake Project study during the period March 1965 to April 1966 were to determine the role of the watershed as a source of algal nutrients and to learn if one or more nutrients could be diverted and, thereby, limit the growth of algae. Future objectives were to examine potential chemical, physical, and biological methods for controlling algae.

This interim report presents information on (a) inorganic elements known to serve as nutrients for some groups of algae; (b) biota that affect the growth of algae; (c) measurements of inflow and outflow of Upper Klamath Lake; (d) hydrographic characterizations of the Upper Klamath Lake drainage basin, and (e) other studies that are needed to increase knowledge as to the sustenance of nuisance blooms of algae and means for controlling them.

## SUMMARY AND CONCLUSIONS

### A. Summary

The study to date has accomplished the following:

The water quality and nutrient loading of the watershed have been defined.

The pristine mountain water, major tributaries, and agricultural drainages all contribute phosphorus, nitrogen, and iron.

The loading pattern of the watershed shows that the combined sources of the Wood and Williamson Rivers drainage systems contribute 43 to 79 percent of the inflowing nutrients into Upper Klamath Lake.

To date, no single source of an essential nutrient has been found.

Studies to define the trends of nitrogen, phosphorus, and iron before, during, and after algal blooms did not show the classical ratio of nutrient decline to increased algal production.

Agricultural drainage contributed approximately 20 percent of the nitrogen, 10 percent of the iron, and 26 percent of the phosphorus entering Upper Klamath Lake during the period March 1965 to April 1966.

The quantity of nitrogen and phosphorus contained in only the upper 1 inch of lake-bottom sediments is equal to the amount which would flow into the lake during the next 60 years if the present rate of inflow continues. It is imperative to know the extent to which nutrients in the sediments can interchange with overlying waters.

Collections of algae from the Upper Klamath Lake during 1965 and 1966 showed that Aphanizomenon flos-aquae represented about 90 to 99 percent of the total algal crop during the summer.

Periods of abundance of phytoplankton (mostly Aphanizomenon flos-aquae) were similar in 1957 and in 1965, indicating a somewhat stable ecosystem in Upper Klamath Lake for at least this period of time.

The total tons of nutrients tied up in bottom fauna represented less than 0.1 percent of the available nutrients in the lake and its bottom muds.

Trace element analyses of water from the lake, Williamson River, Denny Creek, and from bottom sediments of the lake indicate that these areas have concentrations of copper, molybdenum, cobalt, zinc, and manganese that are adequate to support nuisance blooms of some algae if other elements are present in sufficient supply.

B. Conclusions

The following conclusions can be made within the framework of our existing knowledge:

Although it is likely that complete chemical control of algae in Upper Klamath Lake would be expensive, annual limited application of algicides to small areas might provide temporary relief. Algicides must be applied with extreme caution to insure the preservation of the ecologic system during and after application.

No biological control of the algal production is yet known. Blue-green algae that dominate Upper Klamath Lake are not palatable to known organisms that ordinarily feed on algae; the possibility of introducing a grazer that would effectively control algal production will be considered.

Physical control of algae has been in practice for some time. Algal growth might be reduced through deepening of the lake by dredging. This method of control would be costly unless the dredging were justified for other purposes such as obtaining a larger holding capacity for the lake or for increasing hydroelectric power.

The inorganic nutrient concentrations found in Upper Klamath Lake meet or exceed the levels known to be necessary for the support of nuisance blooms of some algae.

Research is needed to define the minimum concentration and quantity of inorganic nutrients necessary to support the production of nuisance blooms of Aphanizomenon flos-aquae.

Data from experiments on limiting nutrients were difficult to interpret. This difficulty indicates a need to study the requirements of the algae in question in pure cultures where known amounts of elements are present in the culture medium and where these algae can be more precisely manipulated.

## HYDROLOGY

Hydrology as applied to the Klamath Lake Project deals with surface water circulation in the Upper Klamath Lake drainage basin. The Upper Klamath Lake hydrologic unit, including Crater Lake 1/, has a drainage area of 3,810 square miles, and is located in the Modoc-Oregon geomorphic province which includes the southern portion of the eastern Cascades and adjacent high mountain plateaus and valleys.

Upper Klamath Lake has a mean depth of 8 feet and a storage capacity of 584,000 acre-feet. Some of the lake bed has been reclaimed by diking. The lake serves as a reservoir for irrigation water and for electrical power production. The altitude of the lake surface is controlled between 4,136 and 4,143 feet. The controlled outflow passes steeply down the Link River less than 2 miles in length into Lake Ewauna at Klamath Falls. The lake is subject to wind action and shows no evidence of physical or chemical stratification. Water enters Upper Klamath Lake from pristine mountain streams, rivers, irrigation canals, agricultural drainage, springs, and by precipitation.

The U. S. Geological Survey operated 13 continuous stream-flow gaging stations during the period March 1965 to April 1966. Figure 1 shows these gaging stations. Klamath Lake Project personnel installed flow-monitoring equipment on 90 percent of the irrigation waters and 80 percent of the agricultural drainage waters for the area. The locations of this equipment for the agricultural drainage are shown as sumps in Figure 1 and those for the irrigation waters are near the sumps.

The U. S. Geological Survey furnished monthly basic hydrologic reports which were used for the computation of monthly and annual water budgets. Table 1 presents the water budget for Upper Klamath Lake for the period March 1965 to April 1966. Six major tributaries, including springs, contributed 90 percent of the inflow to the lake; four minor tributaries which are small and intermittent are included in the water budget. The water budgets were used for the compilation of monthly and annual inorganic (nutrient) loads contributed to Upper

1/ Most maps arbitrarily place Crater Lake in the drainage basin of the Klamath River, but the actual direction of its leakage is unknown; the lake could be considered as contributing to the Rogue River or to the Umpqua River.

TABLE 1
WATER BUDGET, MARCH 1965 TO APRIL 1966
UPPER KLAMATH LAKE

| Source | CFS-Days | Total Acre-Feet | Percent of Total |
|---|---|---|---|
| Incoming | | | |
| Denny Creek | 4,500 | 8,930 | 0.4 |
| Varney Creek | 888 | 1,760 | 0.1 |
| Fourmile Creek | 5,470 | 10,850 | 0.5 |
| Rock Creek | 1,310 | 2,600 | 0.1 |
| Fourmile Canal | 21,550 | 42,740 | 2.0 |
| Seven Mile Canal | 50,720 | 100,600 | 4.6 |
| Central Canal | 12,840 | 25,470 | 1.2 |
| Wood River | 160,370 | 318,090 | 14.7 |
| Williamson River | 503,820 | 999,310 | 46.2 |
| Crooked Creek | 36,250 | 71,900 | 3.3 |
| Agricultural drainage | 55,790 | 110,650 | 5.1 |
| Precipitation | 48,040 | 95,290 | 4.4 |
| Estimated springs | 189,590 | 376,060 | 17.4 |
| Total Gain | 1,091,140 | 2,164,250 | 100.0 |
| Outgoing | | | |
| Link River & 'A' Canal | 851,620 | 1,689,170 | 78.0 |
| Evapotranspiration | 222,980 | 442,280 | 20.4 |
| Irrigation pumpage & diversion | 16,540 | 32,800 | 1.5 |
| Total Loss | 1,091,140 | 2,164,250 | 99.9 |

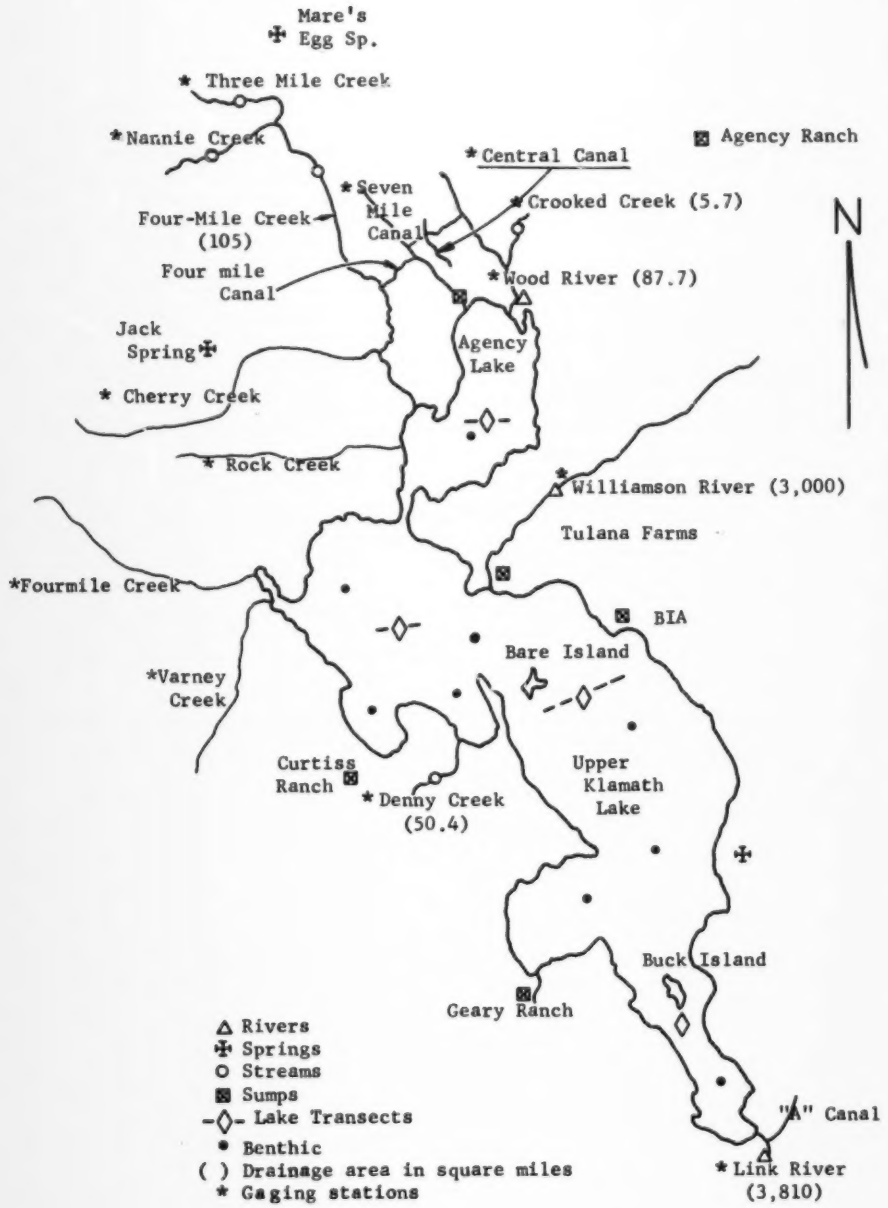


FIGURE 1
UPPER KLAMATH LAKE AND ITS TRIBUTARIES

Klamath Lake from each representative source of inflow. The inorganic nutrient budget for each of these sources is shown in Table 2. In most cases, the total amount of nutrient entering the lake is equal or almost equal to the total amount of the same nutrient leaving the lake for the same period. If the loss is greater than 10 percent of the total incoming, it is considered significant.

Only two elements, nitrogen and iron, showed significant losses. Three hundred four tons of total iron were lost from the system. This represents 1.4 times more iron in the outgoing water than there is in the incoming water. Possible explanations for the large loss of iron from the lake may be: (a) wind action during the months of September through December of 1965 caused the suspension of bottom materials, causing concentrations of total iron leaving the system to be almost five times greater than those entering the lake, and (b) larger amounts of water left the lake than came in during this period.

Eighteen hundred sixty tons of total nitrogen were lost from the system. This is 2.6 times more nitrogen in the outgoing water than there is in the incoming water. Possible explanations for this nitrogen loss may be: (a) same as above for iron; (b) nitrogen fixation may account for large amounts of nitrogen in the system, and (c) decomposition products of algae, which included ammonia and nitrate nitrogen, were present during this period of increased outflow from the system.

The percentage of inflow into Upper Klamath Lake from each representative source for the period March 1965 to April 1966 is presented in Table 3. The Williamson River, the major tributary to the lake, contributed 46 percent of all incoming water to Upper Klamath Lake during the reporting period.

TABLE 2
INORGANIC NUTRIENT BUDGET FOR UPPER KLAMATH LAKE
MARCH 1965 TO APRIL 1966
EXPRESSED IN TONS

| Constituent | Pristine Streams | Canals | Rivers | Agricultural Drainage | Springs | Total Incoming | Total Outgoing | Balance |
|---|---|---|---|---|---|---|---|---|
| Boron | 1 | 11 | 138 | 12 | 97 | 259 | 172 | 87 |
| Calcium | 132 | 1,652 | 16,276 | 1,884 | 3,478 | 23,422 | 23,477 | -55 |
| Chloride | 18 | 253 | 4,369 | 226 | 1,432 | 6,298 | 4,600 | 1,698 |
| Iron | 2 | 86 | 687 | 86 | 2 | 863 | 1,167 | -304 |
| Magnesium | 31 | 295 | 2,594 | 508 | 1,534 | 4,962 | 4,058 | 904 |
| Nitrogen | 4 | 118 | 702 | 241 | 137 | 1,202 | 3,062 | -1,860 |
| Potassium | 12 | 284 | 2,259 | 323 | 716 | 3,594 | 3,227 | 367 |
| Total $PO_4$ as P | 2 | 26 | 216 | 133 | 125 | 502 | 298 | 204 |
| Silica | 602 | 4,005 | 47,857 | 814 | 14,320 | 67,598 | 54,671 | 12,927 |
| Sodium | 129 | 1,260 | 15,911 | 1,794 | 3,785 | 22,879 | 21,754 | 1,125 |
| Sulfate | 78 | 373 | 5,480 | 2,075 | 1,637 | 9,643 | 9,752 | -109 |

TABLE 3
PERCENTAGE OF INFLOW INTO UPPER KLAMATH LAKE
FROM EACH REPRESENTATIVE SOURCE
MARCH 1965 TO APRIL 1966

| Source | Percentage |
|---|---|
| Pristine streams | 1.1 |
| Canals | 7.8 |
| Agricultural drainage | 5.1 |
| Major rivers | 64.2 |
| Springs | 17.4 |
| Precipitation | 4.4 |

Link River and "A" Canal represented 78 percent of the outflow from Upper Klamath Lake while evapotranspiration and irrigation pumpage including diversion represented 20 and 1.5 percent, respectively, during the reporting period.

## CHEMISTRY

### A. Methods

#### 1. Sampling

All stream samples were depth-integrated at midpoint of flow. Lake samples were composited along a transect of the sampling site. Each composite consisted of four vertically integrated samples collected by a Plexiglas cylinder, 1 3/4 inches x 8 feet. The stream and agricultural drainage sampling stations are shown in Figure 1 at the same location as the gaging stations and sumps; the lake sampling stations are at the locations designated "Lake Transects".

#### 2. Analytical Methods

Most chemical methods were selected from "Standard Methods," (2). Minor modifications were made in certain procedures to enhance the analyses. Modifications were verified with related methods outlined in "Standard Methods."

The following parameters were determined:

| Parameter | Method |
|---|---|
| Alkalinity ($HCO_3$, $CO_3$, and OH) | Potentiometric (2) |
| Ammonia Nitrogen | Distillation/Nesslerization (2) |
| Boron | Curcumin (2) |
| Calcium | EDTA (2) |
| Chloride | Mercuric nitrate (2) |
| Total Hardness | EDTA (2) |
| Iron (Total & Dissolved) | 1, 10-Phenanthroline (2) |
| Magnesium | Calculation (22) |
| Manganese | Ammonium persulfate (22) |
| Nitrate Nitrogen | Modified Brucine (2) |
| Nitrite Nitrogen | (2) |
| Organic Nitrogen | Kjeldahl (2) |
| Phosphate-Ortho (as P) | Stannous chloride (2) |
| Phosphate-Total (as P) | Persulfate modification (2) |
| pH | Electrometric (2) |
| Potassium | Flame photometric (2) |
| Sodium | Flame photometric (2) |
| Sulfate | Turbidimetric (2) |
| Total Solids, and Total Volatile Solids | Gravimetric (2) |

Analytical determinations were made at the laboratory of the Klamath Lake Project, 2261 South Sixth Street, Klamath Falls, Oregon.

Selected samples for spectrographic trace metal analysis were sent to Robert C. Kroner, Chemist, General Laboratory Services, Water Quality Activities, Basic Data Program, Cincinnati, Ohio.

B. Results and Discussions

1. Watershed

The significance of the watershed as a source of algal nutrients was investigated for the period March 1965 to April 1966. During this period 445 water samples were analyzed. A series of lake-bottom sediments and specific samples of algae, mostly Aphanizomenon, were also analyzed.

The major rivers, the Wood and Williamson, contribute 43 to 79 percent of all incoming nutrients into Upper Klamath Lake. No source of inflow has been found to be the sole contributor of such elements as nitrogen, phosphorus, and iron into the lake system. The representative sources of inflow and their percent nutrient contributions are presented in Table 4. The range in nutrient concentrations expressed in milligrams per liter for each representative source are presented in Table 5. In most cases, the concentrations found in agricultural drainage were considerably higher than those found in major rivers, springs, and pristine streams. Agricultural drainage contributed approximately 20 percent of the nitrogen, 10 percent of the iron, and 26 percent of the phosphorus entering Upper Klamath Lake during the reporting period.

The inorganic nutrient requirements for some algae are listed in Table 6. The information in Tables 5 and 6 indicates that the concentrations of the corresponding elements found in Upper Klamath Lake are sufficient to support nuisance blooms of algae. The sustenance of these blooms may be enhanced by the nutrient concentrations contained in the bottom sediments.

2. Bottom Sediments

Bottom sediments from Upper Klamath and Agency Lakes were chemically analyzed. The quantity of nutrients, expressed in tons, contained in the bottom sediments over an area of 130 square miles at a depth of 1 inch, is shown in Table 7.

The total impact of the bottom sediments in a dynamic eutrophic lake system is not understood. Further investigation is being conducted to determine the chemical interchange between the bottom sediments and overlying water. However, Table 7 shows that there is

TABLE 4
REPRESENTATIVE INFLOWS AND THEIR PERCENT
NUTRIENT CONTRIBUTION, MARCH 1965 TO APRIL 1966

| Constituent | Pristine streams | Agricultural Drainage | Canals | Springs | Major Rivers |
|---|---|---|---|---|---|
| Boron | 0.4 | 5.0 | 4.2 | 37.0 | 53.0 |
| Calcium | 0.6 | 8.0 | 7.0 | 14.8 | 69.4 |
| Chloride | 0.3 | 3.6 | 3.9 | 22.7 | 69.3 |
| Total iron | 0.2 | 10.0 | 9.9 | 0.2 | 79.6 |
| Magnesium | 0.6 | 10.2 | 5.9 | 30.9 | 52.2 |
| Total nitrogen | 0.4 | 20.1 | 9.8 | 11.4 | 58.4 |
| Total phosphorus | 0.4 | 26.5 | 5.1 | 24.9 | 43.0 |
| Potassium | 0.3 | 9.0 | 7.9 | 19.9 | 62.8 |
| Silica | 0.9 | 1.2 | 5.9 | 21.2 | 70.9 |
| Sodium | 0.6 | 7.8 | 5.5 | 16.5 | 69.5 |
| Sulfate | 0.8 | 21.5 | 3.9 | 17.0 | 56.9 |

TABLE 5
NUTRIENT CONCENTRATION RANGES IN MG/L

| Nutrient | Lake | Pristine Streams | Springs | Major Rivers | Agricultural Drainage |
|---|---|---|---|---|---|
| Total Alkalinity | 10 to 55 | 15 to 40 | 30 to 40 | 30 to 45 | 35 to 265 |
| Ammonia Nitrogen | .00 to 1.8 | .00 to .05 | .00 to .06 | .05 to .30 | .00 to 5.7 |
| Boron | .000 to 0.30 | 0 to .25 | .000 to .20 | .000 to .20 | .004 to .35 |
| Calcium | 5 to 15 | 5 to 10 | 5 to 15 | 5 to 12 | 5 to 150 |
| Chloride | 1.9 to 5 | 0.0 to 0.6 | 0.3 to 11 | 0.5 to 6.0 | 0.7 to 10 |
| Cobalt | .005 to .007 | .003 to .005 | | .003 to .005 | |
| Conductivity* | 80 to 225 | 30 to 100 | 65 to 130 | 70 to 100 | 80 to 1000 |
| Copper | .004 to .006 | .003 to .004 | | .004 to .006 | |
| Hardness(Total) | 20 to 35 | 10 to 30 | 20 to 45 | 20 to 35 | 25 to 400 |
| Iron | .000 to 2.5 | .000 to .70 | .000 to .004 | .000 to 2.7 | .000 to 5.5 |
| Lead | .014 to .045 | .010 to .20 | | .000 to .020 | |
| Magnesium | 0.8 to 2.5 | 0.6 to 1.5 | 0.5 to 3.0 | 0.0 to 2.5 | 0.1 to 17 |
| Manganese | .004 to .183 | .003 to .005 | | .014 to .053 | .005 to .20 |
| Molybdenum | .003 to .030 | .000 to .010 | | .000 to .010 | |
| Nitrate Nitrogen | .00 to .20 | .00 to .02 | .00 to .06 | .00 to .10 | .00 to 1.3 |
| Organic Nitrogen | .15 to 10.4 | .00 to .10 | .10 to .25 | .00 to .60 | .05 to 5.5 |
| Total Phosphorus as P | .03 to 2.0 | .00 to .20 | .05 to .24 | .05 to .33 | .08 to 2.0 |
| Potassium | 1.0 to 2.9 | 0.2 to 1.6 | 1.0 to 14 | 1.0 to 2.0 | 1 to 20 |
| Silica | 10 to 35 | 10 to 35 | 20 to 35 | 15 to 35 | 1 to 45 |
| Sodium | 7 to 12 | 1.5 to 4.5 | 3.5 to 16 | 5 to 10 | 6 to 70 |
| Sulfate | 0.0 to 5 | 0.0 to 4.0 | 2.4 to 7.7 | 1.9 to 5.0 | 0.0 to 195 |
| Total Solids | 65 to 240 | 10 to 145 | 70 to 145 | 40 to 165 | 60 to 3000 |
| Total Volatile Solids | 0 to 90 | | 45 to 60 | 0 to 45 | 0 to 555 |
| Zinc | .007 to .058 | .007 to .072 | | .013 to .031 | |

* Expressed in micromhos

TABLE 6
ALGAL REQUIREMENTS FOR INORGANIC ELEMENTS

| Chemical | Range | Percent Dry Weight Composition |
|---|---|---|
| Boron | 0.1 mg/l (blue-green)(7) | |
| Calcium | 20.0 mg/l (Anabaena cylindric)(1) | 0.08(Scenedesmus) (14) |
| Cobalt | 0.5 mg/l (blue-green)(4) | 0.0003(Scenedesmus) (20) |
| Copper | 0.006 mg/l (29) | 0.004(Scenedesmus) (14) |
| Iron | 0.00065-5.0 mg/l (24,26) | 0.55(Scenedesmus)(14) |
| Magnesium | (Probably trace quantities) | 0.80(Scenedesmus) (14) |
| Manganese | .005 mg/l (20) | 0.01(Scenedesmus) (14) |
| Molybdenum | Trace quantities | |
| Total nitrogen (6,25) | (0.3-5.3 mg/l (As ammonium ions) (0.3-0.9 mg/l (nitrate) | 2.77-11.13) )as N(3) ) |
| Phosphorus | 0.018-0.09 mg/l (5,6,25) | 0.14-1.60 (3,11,19) |
| Potassium | (Probably trace quantities) | 1.62(Scenedesmus) (14) |
| Silica | 0.5-0.8 mg/l (diatoms) (15) | 0.012 (Table 8 ) |
| Sodium | Up to 5 mg/l (Anabaena sp)(17) | 0.29 (mixed algae) (Table 8 ) |
| Zinc | 0.01-0.1 mg/l (21) | 0.004(Scenedesmus) (14) |

a tremendous potential source of algal nutrients in the bottom sediments of the lake. The quantity of nitrogen and phosphorus in only the upper 1 inch of lake sediments is as great as that quantity which would flow into the lake during the next 60 years if the present rate of inflow continues. This, of course, assumes no change in quality or quantity of water entering the lake during the next 60 years. Because of this relationship, it is imperative to know the extent to which nutrients in the sediments can interchange with overlying water.

3. Algae

Representative samples of algae from Upper Klamath Lake containing 90 to 99 percent Aphanizomenon flos-aquae have been analyzed for the constituents listed in Table 8. The Kjeldahl nitrogen, calcium, potassium, and total phosphorus content of the algae compares favorably with work done by Phinney (18).

The tons of constituents contained in the algal mass in Upper Klamath Lake for the period March 1965 to April 1966 are presented in Table 8.

The algal mass contained quantities of iron and phosphorus equal to 54 and 25 percent, respectively, of the incoming load entering Upper Klamath Lake during the reporting period. The total nitrogen in the algal mass was 9.4 times greater than the total quantity of nitrogen entering Upper Klamath Lake from all inflow sources for the same period. The source of the nitrogen contained in the algal mass may be from: (a) nitrogen fixation and (b) chemical interaction between the bottom sediments and overlying lake water. Previous investigation (30) has shown that Aphanizomenon sp. does not fix nitrogen. Other workers are presently evaluating the nitrogen fixation abilities of Aphanizomenon sp. 1/ Studies to define the trends of nitrogen, phosphorus, and iron before, during, and after algal blooms did not show the classical ratio of nutrient decline to increased algal production. This may reflect the great surplus of nutrients in relation to rate of uptake by algae combined with replenishment from the bottom sediment as use proceeds.

Research is needed to define the minimum concentration of inorganic nutrients necessary to support the production of nuisance blooms of Aphanizomenon flos-aquae.

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1/ Personal Communications: Dr. Constance Delwiche, University of California, Davis, California.

TABLE 7
BOTTOM SEDIMENT ANALYSES (ACID SOLUBLE)

| Constituent | Micrograms/gram Dry Weight | Tons in Lake Area 1 Inch Deep |
|---|---|---|
| Aluminum | 1,750 | 34,665 |
| Barium | 25 | 496 |
| Beryllium | 0.04 | 0.8 |
| Boron | 98 | 1,942 |
| Cadmium | 14 | 28 |
| Calcium | 3,900 | 77,271 |
| Chromium | 4 | 79 |
| Cobalt | 7 | 139 |
| Copper | 4 | 79 |
| Iron | 11,400 | 225,870 |
| Lead | 14 | 278 |
| Manganese | 183 | 3,626 |
| Nickel | 7 | 139 |
| Ammonia Nitrogen as N | 270 | 5,349 |
| Nitrate Nitrogen as N | 150 | 2,972 |
| Organic Nitrogen as N | 3,400 | 67,364 |
| Total Phosphorus as P | 1,600 | 31,701 |
| Potassium | 1,560 | 30,910 |
| Silicon as Si | 24,000 | 475,517 |
| Silver | 0.70 | 14 |
| Sodium | 780 | 15,453 |
| Strontium | 5 | 99 |
| Sulfur as S | 2,500 | 49,533 |
| Vanadium | 14 | 28 |
| Zinc | 14 | 28 |

TABLE 8
CHEMICAL ANALYSES OF ALGAE FROM UPPER KLAMATH LAKE,
AND THE TONS OF CONSTITUENT IN ALGAL MASS
FOR THE PERIOD MARCH 1965 TO APRIL 1966

| Constituent | Percentage Composition(a) | | Tons In Lake (a) |
|---|---|---|---|
| | Klamath Falls Lab | Literature (18) | |
| Boron | 0.0088 | -- | 8.3 |
| Calcium | 0.602 | 0.54 | 1047 |
| Chloride | 0.42 | -- | 385 |
| Total iron | 0.510 | -- | 466 |
| Magnesium | 0.151 | -- | 138 |
| Manganese | 0.0056 | -- | 5.4 |
| Ammonia Nitrogen as N | 0.022 | -- | 20 |
| Nitrate Nitrogen as N | 0.017 | -- | 15 |
| Organic Nitrogen as N | 12.320 | 10.05 | 11,281 |
| Total Phosphate as P | 0.43 | 0.60 | 128 |
| Potassium | 0.95 | 1.08 | 870 |
| Silica | 0.012 | -- | 11 |
| Sodium | 0.29 | -- | 265 |
| Sulfate | 0.795 | -- | 728 |

(a) Based on dry weight

4. Trace Elements

The complex physical and chemical equilibrium between monovalent and polyvalent cations and its relationship to algal production is not known. The role of "organics," including humates, in the chelation of polyvalent metals to increase their ability to enhance or inhibit the metabolism of algae is not understood.

One concept for ecological control of algal blooms assumes that algal growth can be impaired if a trace element, necessary in minute quantities as a vital micronutrient, can be withheld. In pursuit of this concept, the availability of candidate micronutrients was examined.

Trace element analyses of water from the lake, Williamson River, Denny Creek, and from bottom sediments of the lake (Tables 7, 9-11) compared with Table 6 indicate that these areas have concentrations of copper, molybdenum, cobalt, zinc, and manganese that are adequate to support nuisance blooms of some algae if other elements are present in sufficient supply.

TABLE 9
SPECTROGRAPHIC ANALYSES, LINK RIVER OUTFLOW

| Constituent | Suspended Material micrograms/l | Dissolved Material micrograms/l |
|---|---|---|
| Zinc | 13 | 34 |
| Cadmium | <10 | <10 |
| Arsenic | - a/ | <50 |
| Boron | 13 | 52 |
| Phosphorus | - | 125 |
| Iron | 500 | 210 |
| Molybdenum | <10 | 20 |
| Manganese | 4 | 26 |
| Aluminum | 525 | 104 |
| Beryllium | < 0.03 | < 0.03 |
| Copper | 4 | 5 |
| Silver | < 0.5 | < 0.5 |
| Nickel | < 5 | < 5 |
| Cobalt | < 5 | < 5 |
| Lead | 35 | 38 |
| Chromium | 5 | 6 |
| Vanadium | <10 | <10 |
| Barium | 10 | 12 |
| Strontium | < 1 | 38 |

a/ Interference from high iron

TABLE 10
SPECTROGRAPHIC ANALYSES, WILLIAMSON RIVER

| Constituent | Suspended Material micrograms/l | Dissolved Material micrograms/l |
|---|---|---|
| Zinc | 13 | 28 |
| Cadmium | <10 | <10 |
| Arsenic | - a/ | <50 |
| Boron | 43 | 34 |
| Phosphorus | - a/ | 150 |
| Iron | >1,000 | 362 |
| Molybdenum | - b/ | <10 |
| Manganese | 14 | 34 |
| Aluminum | >1,500 | 256 |
| Beryllium | < 0.03 | < 0.03 |
| Copper | 6 | 4 |
| Silver | 0.5 | < 0.5 |
| Nickel | < 5 | 5 |
| Cobalt | < 5 | 5 |
| Lead | 20 | 12 |
| Chromium | 5 | 6 |
| Vanadium | <10 | <10 |
| Barium | 12 | 24 |
| Strontium | < 1 | 38 |

a/ Interference from high iron
b/ Interference from high aluminum

TABLE 11
SPECTROGRAPHIC ANALYSES, DENNY CREEK

| Constituent | Suspended Material micrograms/l | Dissolved Material micrograms/l |
|---|---|---|
| Zinc | 7.0 | 72 |
| Cadmium | <10 | <10 |
| Arsenic | - a/ | 50 |
| Boron | 11 | 9 |
| Phosphorus | - a/ | 75 |
| Iron | 400 | 135 |
| Molybdenum | <10 | <10 |
| Manganese | < 3 | 5 |
| Aluminum | 460 | 75 |
| Beryllium | < 0.03 | < 0.03 |
| Copper | < 3.0 | 4.0 |
| Silver | < 0.5 | < 0.5 |
| Nickel | < 5.0 | < 5.0 |
| Cobalt | < 5.0 | < 5.0 |
| Lead | 20 | <10 |
| Chromium | < 3 | < 3 |
| Vanadium | <10 | <10 |
| Barium | 9.0 | 11 |
| Strontium | < 1.0 | 20 |

a/ Interference from aluminum

## BIOLOGY

### A. Methods

Samples for algal analyses were taken at the same times, places, and in the same manner as chemical samples. Samples for benthic animal analyses were taken with an Ekman dredge from various points in the lake (Figure 1).

To concentrate the phytoplankton, a method of centrifugation similar to that used by Mackenthun et al. (16) was employed. From aggregate samples, 100-ml portions of water were poured into each of eight 100-ml centrifuge tubes; 5 ml of a liquid detergent (GSA grade) were added to each tube to settle the algae. These tubes were spun at 1500 r.p.m. for 20 minutes. The supernatant liquid was decanted and the concentrate was transferred with a pipet to Constable tubes graduated in 0.005-ml increments. The Constable tubes were spun at 2000 r.p.m. for 10 minutes. The amount of concentrate in the Constable tubes was measured and the quantity of aggregate sample in terms of milliliters per liter was calculated. The concentrate was then transferred to a tared drying pan, dried at 90° C for 6 hours, and weighed.

The volumes of concentrated material in the Constable tubes varied according to the density of various components in suspension in the sample at the time it was taken. Therefore, dry weights were considered to give a more accurate estimate of the material in the aggregate samples.

Benthic fauna were screened and picked and the percent composition of various major groups was estimated. Dry weights of individual samples were recorded after drying for 4 hours at 110° C.

Chlorophyll *a* values were determined using methods outlined in Strickland and Parsons (28).

Limiting nutrient studies [1/] using the isotope Carbon-14 to measure the variations in primary productivity were conducted *in situ*

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1/ Any condition which is above or below the limits of tolerance for any organism is said to be a limiting factor. Therefore, nutrient elements in the aquatic environment that are so abundant as to be toxic and prevent algal growth or are so rare that algae cannot grow are considered limiting nutrients.

and in the laboratory using techniques similar to those of Goldman (12). In the field, samples of lake water with the natural concentrations of algae were cultured *in situ* with additions of elements listed in Table 12 and with $^{14}C$ having an activity of 6.0 millicuries. In each experiment, one sample was inoculated only with $^{14}C$ as a control and other samples were inoculated with $^{14}C$ and with varying concentrations of elements (Table 12). Variations in the amounts of $^{14}C$ uptake by the samples (other than in the control) were analyzed to determine if there were no response, inhibition, or increased productivity (Table 13). Personnel in Charles Goldman's laboratory at Davis, California (University of California) counted the uptake of $^{14}C$ from filters of the various samples and returned the data to Klamath Falls. The data were calculated in uptake of $^{14}C$ in counts per second. The laboratory experiments differed from the field experiments only in that water from the lake was incubated under cool-white fluorescent lights at 16.0° C with constant rotatory movements. Samples in the field or in the laboratory were incubated for 4-hour periods.

B. Results and Discussion

Upper Klamath Lake has annual blooms of blue-green algae that reach nuisance proportions. Recorded history offers little insight into the length of time that nuisance blooms have occurred in Upper Klamath Lake. However, as early as 1933, collections from the lake showed blue-green algae to be dominant (18). Algae collected in 1933 were dominated by *Anabaena spiroides* var. *crassa*. Collections taken in 1957 and 1958 were dominated by *Aphanizomenon flos-aquae* (18). Although *A. flos-aquae* has dominated the algal blooms during the past few summers, other blue-green species have also become important components of the summer bloom. Phinney (18) listed the following species of blue-green algae that have been important segments of algal blooms in Upper Klamath Lake:

*Aphanizomenon flos-aquae* (=Phinney's *A. oregonensis*)
*Anabaena spiroides* var. *crassa* (=*A. circinalis*)
*Microcystis* (*Polycystis*) *aeruginosa*
*Gloeotrichia echinulata*

The usual pattern of seasonal change for algal species in lakes and impoundments is a spring bloom of diatoms, green algae in early summer, blue-green algae in mid and late summer, and a return to diatoms in late fall and early winter. This pattern is not followed in Upper Klamath Lake. Here, the early winter through late spring algae are similar to the above pattern, but in late spring, blue-green algae increase and are dominant from March through November.

TABLE 12
LIMITING NUTRIENT EXPERIMENTS USING $^{14}C$ TO MEASURE VARIATIONS IN PRIMARY PRODUCTIVITY
(LABORATORY AND IN SITU EXPERIMENTS)

| Date | Area | Element | Element Form | Mg/l of Element Added | $^{14}C$ Uptake a/ |
|---|---|---|---|---|---|
| 10/11/66 | Lab | $NO_3$ | $KNO_3$ | 0.033 | 79 |
| | | | | 0.066 | 58 |
| | | | | 0.099 | 90 |
| | | | | 0.132 | 82 |
| 10/11/66 | Lab | $NO_3$ | $NaNO_3$ | 0.033 | 75 |
| | | | | 0.066 | 75 |
| | | | | 0.099 | 75 |
| | | | | 0.132 | 85 |
| 10/13/66 | Lab | $NO_3$ | $KNO_3$ | 0.000 | 238 |
| | | | | 0.033 | 207 |
| | | | | 0.066 | 210 |
| | | | | 0.099 | 222 |
| 10/13/66 | Lab | $NO_3$ | $NaNO_3$ | 0.033 | 227 |
| | | | | 0.066 | 226 |
| | | | | 0.099 | 199 |
| | | | | 0.132 | 101 |
| 10/14/66 | Lab | $NO_3$ | $KNO_3$ | 0.000 | 911 |
| | | | | 0.033 | 967 |
| | | | | 0.066 | 997 |
| | | | | 0.099 | 1088 |
| 10/14/66 | Lab | $NO_3$ | $NaNO_3$ | 0.033 | 1126 |
| | | | | 0.066 | 1053 |
| | | | | 0.099 | 1152 |
| | | | | 0.132 | 918 |
| 10/17/66 | Lab | $NH_4$ | $CH_3COONH_4$ | 0.000 | 328 |
| | | | | 0.033 | 335 |
| | | | | 0.066 | 275 |
| | | | | 0.099 | 301 |
| 10/17/66 | Lab | Cl | $NH_4Cl$ | 0.033 | 322 |
| | | | | 0.066 | 313 |
| | | | | 0.099 | 288 |

a/Uptake of $^{14}C$ in counts/per second

TABLE 12 (Continued)

| Date | Area | Element | Element Form | Mg/l of Element Added | $^{14}C$ Uptake |
|---|---|---|---|---|---|
| 10/18/66 | Lab | $NH_4$ | $CH_3COONH_4$ | 0.000 | 1312 |
| | | | | 0.033 | 1063 |
| | | | | 0.066 | 699 |
| | | | | 0.099 | 752 |
| 10/18/66 | Lab | Cl | $NH_4Cl$ | 0.033 | 766 |
| | | | | 0.066 | 752 |
| | | | | 0.099 | 691 |
| 10/19/66 | Lab | $PO_4$ | $(NH_4)_2HPO_4$ | 0.33 | 363 |
| | | | | 0.66 | 361 |
| | | | | 0.99 | 351 |
| 10/19/66 | Lab | $P_2O_7$ | $Na_4P_2O_7 10H_2O$ | 0.33 | 404 |
| | | | | 0.66 | 332 |
| | | | | 0.99 | 341 |
| 10/20/66 | Lab | $PO_4$ | $(NH_4)_2HPO_4$ | 0.00 | 1253 |
| | | | | 0.33 | 1265 |
| | | | | 0.66 | 1298 |
| | | | | 0.99 | 1344 |
| 10/20/66 | Lab | $P_2O_7$ | $Na_4P_2O_7 10H_2O$ | 0.33 | 1281 |
| | | | | 0.66 | 1252 |
| | | | | 0.99 | 1274 |
| 10/24/66 | Lab | Na | NaCl | 0.00 | 92 |
| | | | | 9 | 87 |
| | | | | 18 | 105 |
| | | | | 27 | 111 |
| 10/24/66 | Lab | Na | $NaHCO_3$ | 9 | 76 |
| | | | | 18 | 55 |
| | | | | 27 | 52 |
| 10/25/66 | Lab | Na | NaCl | 0.00 | 443 |
| | | | | 9 | 515 |
| | | | | 18 | 576 |
| | | | | 27 | 504 |
| 10/25/66 | Lab | Na | $NaHCO_3$ | 9 | 435 |
| | | | | 18 | 355 |
| | | | | 27 | 254 |

TABLE 12 (Continued)

| Date | Area | Element | Element Form | Mg/l of Element Added | $^{14}C$ Uptake |
|---|---|---|---|---|---|
| 10/26/66 | Lab | $NH_4$ | $NH_4Cl$ | 0.00 | 216 |
| | | | | 0.70 | 226 |
| | | | | 1.4 | 234 |
| | | | | 2.1 | 244 |
| | | | | 2.8 | 233 |
| 10/26/66 | Lab | Fe | FeCitrate | 0.30 | 241 |
| | | | | 0.60 | 253 |
| | | | | 0.90 | 220 |
| 10/27/66 | Lab | $NH_4$ | $NH_4Cl$ | 0.00 | 1009 |
| | | | | 0.70 | 975 |
| | | | | 1.4 | 997 |
| | | | | 2.1 | 1128 |
| | | | | 2.8 | 1378 |
| 10/27/66 | Lab | Fe | FeCitrate | 0.30 | 987 |
| | | | | 0.60 | 1168 |
| | | | | 0.90 | 1028 |
| 8/4/66 | Field | $NO_3$ | $KNO_3$ | 0.000 | 1477.19 |
| | | | | 0.025 | 1488.64 |
| | | | | 0.050 | 1200.85 |
| | | | | 0.075 | 1220.61 |
| 8/22/66 | Field | $NO_3$ | $NaNO_3$ | 0.000 | 123.50 |
| | | | | 0.025 | 123.70 |
| | | | | 0.050 | 120.30 |
| | | | | 0.075 | 107.14 |
| 8/23/66 | Field | $NH_4$ | $NH_4Cl$ | 0.000 | 74.41 |
| | | | | 0.50 | 81.58 |
| | | | | 1.00 | 87.03 |
| | | | | 1.50 | 93.18 |
| 8/24/66 | Field | $PO_4$ | $KH_2PO_4$ | 0.00 | 91.55 |
| | | | | 0.43 | 79.30 |
| | | | | 0.86 | 76.91 |
| | | | | 1.29 | 70.03 |

TABLE 12 (Continued)

| Date | Area | Element | Element Form | Mg/l of Element Added | $^{14}C$ Uptake |
|---|---|---|---|---|---|
| 8/25/66 | Field | $P_2O_7$ | $NaP_2O_7 10H_2O$ | 0.00 | 186.10 |
| | | | | 0.43 | 167.38 |
| | | | | 0.86 | 144.68 |
| | | | | 1.29 | 137.77 |
| 10/1/66 | Field | FeCitrate | Ferric Citrate | 0.00 | 86.35 |
| | | | | 0.30 | 85.55 |
| | | | | 0.60 | 61.33 |
| | | | | 0.90 | 60.39 |

Collections of algae from Upper Klamath Lake during 1965 and 1966 showed Aphanizomenon flos-aquae representing about 90 to 99 percent of the total algal crop during the summer. Unialgal blooms are not common but have been recorded by other workers (9). The annual patterns of algal cycles in Upper Klamath Lake have been much the same since at least 1956 when Phinney (18) showed A. flos-aquae as the dominant summer bloom. Figure 2 compares dry weights (in milligrams per liter) of phytoplankton 2/ made of collections taken in 1965 and counts of algal cells made by Phinney (18) from collections taken in 1957. The similarity of the curves indicates that periods of phytoplankton abundance were similar in the two years.

Figure 3 shows the average tons of algae present in Upper Klamath Lake for 1965 and part of 1966 and the average tons of carbon assimilated per hour by the algae for part of 1965 and 1966. The average tons of carbon assimilated per hour during the photosynthetic period were calculated from chlorophyll a data using a factor of 3.7 mg carbon being fixed per hour per mg chlorophyll a (23). However, this factor must be used with caution as it was based on data taken from marine collections, and the factor for converting chlorophyll a to total plant carbon can vary between about 20 and 70 (28). Taking the above limitations into consideration, Figure 3 can be interpreted in a general manner to indicate that there is a high potential for primary productivity in Upper Klamath Lake. Findenegg (8) has pointed out that:

> "The effect of production of a given quantity of algae varies from hour to hour. It may be reduced by increase and decrease of the light intensity to which the species are adapted.... In most cases an inverse correlation was found between the quantity of algal biomass and production per unit of freshweight. Below one square meter of lake surface 1 g of phytoplankton assimilated 0.4 g carbon per day when only small quantities of algae were present but only thousandth (sic) when crowded masses of cells were present."

Although Findenegg's data were from marine observations where production is usually much lower than in freshwater, the same principles apply, which indicates a need for much caution in interpreting Figure 3 too liberally.

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2/ The dry weights were really of all suspended matter, but visual observations under the microscope showed that at least 90+ percent of the material was made up of algae.

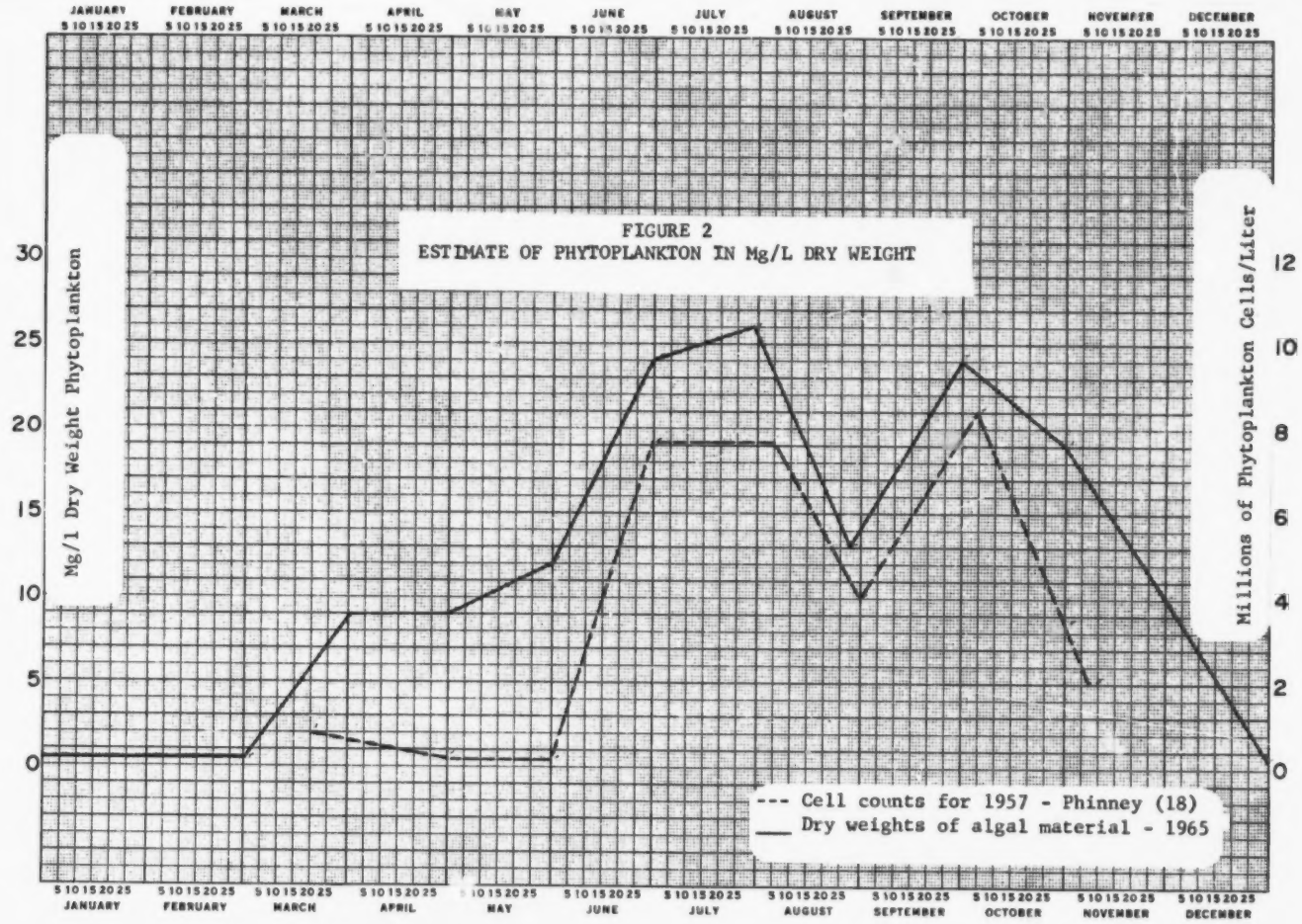
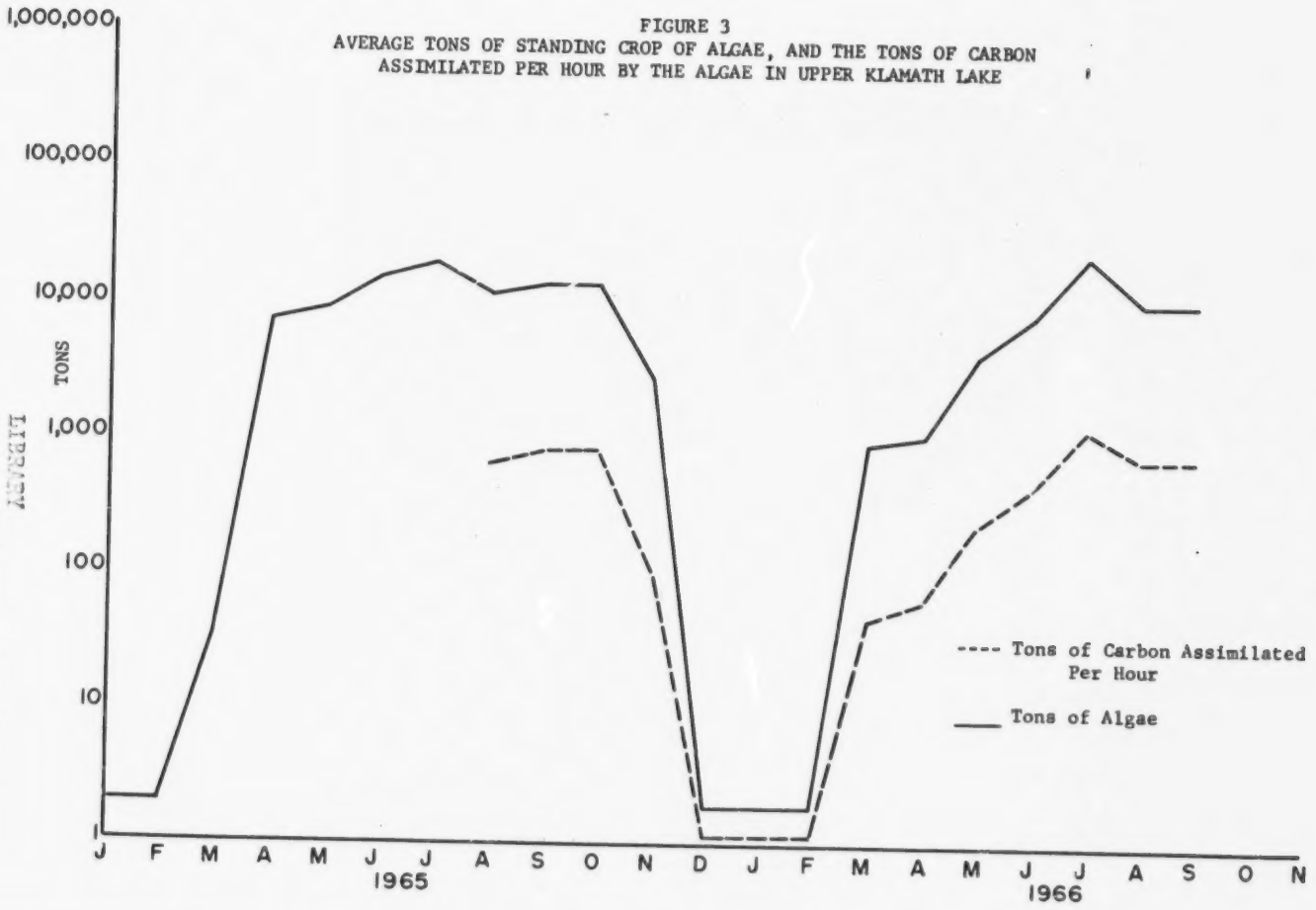



FIGURE 2
ESTIMATE OF PHYTOPLANKTON IN Mg/L DRY WEIGHT

FIGURE 3
AVERAGE TONS OF STANDING CROP OF ALGAE, AND THE TONS OF CARBON ASSIMILATED PER HOUR BY THE ALGAE IN UPPER KLAMATH LAKE




LIBRARY
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1. Limiting Nutrient Studies

Results from the limiting nutrient studies are shown in Table 12. Although there were many variations in amounts of $^{14}C$ assimilated by the addition of different amounts of nitrate, ammonia, phosphorus, iron, and sodium, it is difficult to interpret the causes for the variations. Goldman (13) stated:

> "In my experience, it is not at all uncommon to find inhibition by trace element additions at as low a level as 1 µg/liter. Although environmental levels of one or more trace elements may be at toxic or near toxic levels for most algae, we still find certain species which apparently thrive under these conditions. Adding more of an element already at an unfavorably high level is likely to produce an inhibition, and it is probable that particular species or races have developed which are especially adapted to these toxic levels, in the same manner that the low levels of certain elements may favor other species."

He also stated that negative responses should be compared with elemental analyses of the water involved, giving particular attention to possible interaction of the various metals. However, in waters such as Upper Klamath Lake where unknown amounts and qualities of many organic and some inorganic constituents occur with large amounts of known inorganic elements, it becomes difficult to locate and isolate causative agents for negative, positive, or lack of response, especially when variations of such responses occur even after repeating the same test several times. In field experiments with nitrate, ammonia, phosphorus, and iron, all additions of the various substances in different forms showed inhibitory responses except for ammonia which was positive (Table 13). In different tests where $CH_3COONH_4$, and $Na_4P_2O_7 \cdot 10H_2O$ were added in the same concentrations, some of the tests showed no response and others inhibitory or increased productivity responses (Table 13). The difficulty in interpreting these data indicates a need to study the requirements of the algae in question in pure cultures where known amounts of elements are present in the culture medium and can be more precisely manipulated. Goldman (13) pointed out that there is a possibility of controlling algal populations in nature by increasing one or more nutrients that have been found to produce inhibition. Sufficient knowledge of algal physiology is not now available to permit this.

2. Bottom Fauna

Analyses of bottom fauna in Upper Klamath Lake during 1964-1965 are presented in Table 14. The data are too limited to allow interpretation of the differences observed from 1964 to 1965, but are sufficient to show that the total tons of bottom fauna comprise less than 0.1 percent of the available nutrients in the lake and its

TABLE 13
RESPONSE OF ALGAE IN UPPER KLAMATH LAKE CAUSED BY
THE ADDITION OF VARIOUS INORGANIC ELEMENTS (TABLE 12)
AS MEASURED BY CARBON-14 UPTAKE a/

| Element | Form of Element | Field Experiments | Test 1 | Test 2 | Test 3 | Test 4 |
|---|---|---|---|---|---|---|
| Nitrate | $KNO_3$ | (-) | 0 | 0 | 0 | |
| | $NaNO_3$ | (-) | 0 | (-) | 0&+ | |
| Ammonia | $NH_4Cl$ | + | 0 | 0 | 0 | 0 |
| | $CH_3COONH_4$ | | 0 | (-) | | |
| Phosphorus | $(NH_4)_2HPO_4$ | | 0 | 0 | | |
| | $KH_2PO_4$ | (-) | | | | |
| | $Na_4P_2O_7 \cdot 10H_2O$ | (-) | (-) | 0 | | |
| Iron | Ferric Citrate | - | 0 | 0 | | |
| Sodium | NaCl | | 0 | 0 | | |
| | $NaHCO_3$ | | (-) | (-) | | |

a/ 0 = no response
(-) = inhibitory response
+ = increased productivity

bottom muds. However, bottom fauna may be important as intermediaries in the recycling of various elements between sediment and overlying water. A study of various types of bottom fauna to determine the role they play in recycling should result in a better understanding of the interchange of algal nutrients between sediment and water.

TABLE 14
TONS OF BOTTOM FAUNA IN LAKE

| No. of Samples | Date | Nitrogen as N | Phosphorus as P | Tons Bottom Fauna |
|---|---|---|---|---|
| 72 | 6-64 | 125 | 12 | 1,352 |
| 10 | 7-65 | 50 | 4.6 | 545 |
| 11 | 8-65 | 132 | 12 | 1,425 |
| 11 | 9-65 | 112 | 10 | 1,517 |

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In its assigned function as the Nation's principal natural resource agency, the Department of the Interior bears a special obligation to assure that our expendable resources are conserved, that renewable resources are managed to produce optimum yields, and that all resources contribute their full measure to the progress, prosperity, and security of America, now and in the future.

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